^{39}Ar-^{40}Ar Ages of Two Nakhlites, MIL03346 and Y000593: A Detailed Analysis.

Jisun Park, Daniel Garrison[2], and Donald Bogard, ARES code KR, NASA Johnson Space Center, Houston, TX 77058. ([2]ESCG/Barrios Technology), Jisun.park1@jsc.nasa.gov

Introduction. Radiometric dating of martian nakhlites by several techniques have given similar ages of ~1.2-1.4 Ga [e.g. 1, 2]. Unlike the case with shergottites, where the presence of martian atmosphere and inherited radiogenic ^{40}Ar produce apparent ^{39}Ar-^{40}Ar ages older than other radiometric ages, Ar-Ar ages of nakhlites are similar to ages derived by other techniques. However, even in some nakhlites the presence of trapped martian Ar produces some uncertainty in the Ar-Ar age. We present here an analysis of such Ar-Ar ages from the MIL03346 and Y000593 nakhlites.

Ar-Ar Age Spectra. ^{39}Ar-^{40}Ar ages and K/Ca ratios for whole rock (WR) samples and mineral separates of low magnetic susceptibility (plagioclase plus mesostasis: "Plag") from the MIL03346 and Y000593 nakhlites are shown in Figs. 1 and 2, and are compared with other radiometric ages of these meteorites [3, 4, 5]. All four Ar-Ar spectra show decreasing age with increasing extraction temperature, with most ages being slightly older than the Sm-Nd ages. All age spectra indicate a very small amount of recent diffusion loss of ^{40}Ar. Discounting the low-temperature ^{40}Ar loss, the average (total) Ar-Ar ages in Myr for these four samples are MIL03346 WR =1369, Plag=1413 and Y000593 WR=1397, Plag=1408. The total MIL-WR age is the same as the MIL Sm-Nd age, but the other three Ar ages are a few Myr older than the Sm-Nd ages. All four age spectra also suggest small ^{39}Ar recoil effects at >90% ^{39}Ar release, where an almost constant K/Ca ratio precipitously decreases. Probably pyroxene, even a small amount in the plag mineral separates, acted as the "catcher" for this recoiled ^{39}Ar, thus lowering the apparent age at high temperature. Sloped age spectra as shown in Figs. 1-2 can be produced, in principle, by either release of a trapped martian Ar component or by significant ^{39}Ar recoil produced during neutron irradiation. We use isochron plots to further examine these possibilities.

Isochron Plots of ^{40}Ar/^{36}Ar vs. ^{39}Ar /^{36}Ar were made for all four samples. Ar-Ar ages and trapped ^{40}Ar/^{36}Ar intercept ratios derived from these isochrons are given in Table 1. All Ar-Ar isochron ages are slightly older than the Sm-Nd ages, although several overlap within combined uncertainties. These isochrons were based on the range of ^{39}Ar releases given in Table 1, and those extractions indicating ^{40}Ar diffusion loss or gain of recoiled ^{39}Ar were not included. The ^{36}Ar in these samples is terrestrial at low extraction temperatures, primarily cosmogenic at higher temperatures, and martian at various temperatures. It is usually desirable to correct ^{36}Ar abundances for cosmogenic ^{36}Ar and use only trapped ^{36}Ar in such isochron plots. We make such $^{36}Ar_{cos}$ corrections using the ^{36}Ar/^{37}Ar ratios [6]. However, because of variations in the ^{36}Ar/Ar^{37} ratios with temperature and because cosmogenic ^{36}Ar dominates at higher extraction temperatures, applied corrections for $^{36}Ar_{cos}$ are uncertain. Thus, isochron results resulting from both making $^{36}Ar_{cos}$ corrections and not making such corrections are given in the table. In general, ages and trapped ^{40}Ar/^{36}Ar ratios derived from the two methods are similar, although sometimes they differ by an amount greater than the combined uncertainties. The Sm-Nd isochron ages [3, 4] are also given in Table 1.

Isochron-derived trapped ^{40}Ar/^{36}Ar ratios (Table 1) vary greatly, from +2000 down to -8039. Although all isochrons are strongly linear (R^2>0.99), the uncertainties for most intercepts are relatively large, especially for the Plag. separates where the Ar is highly radiogenic. The most precisely determined trapped ^{40}Ar/^{36}Ar is for Y000593 WR, and the ratio derived by correcting for $^{36}Ar_{cos}$ is similar to trapped ratios determined for some shergottites [7]. Both Y000593 Plag. and MIL03346 WR give negative ^{40}Ar/^{36}Ar ratios, although the uncertainty on the Y593 Plag. ratio, corrected for $^{36}Ar_{cos}$, is much larger than the ratio itself. Often negative ^{40}Ar/^{36}Ar intercepts on an Ar-Ar isochron plot indicate significant ^{39}Ar recoil redistribution. Such an interpretation for MIL03346 WR would be consistent with the strongly sloped age spectrum. However, MIL03346 Plag also shows a partially sloped age spectrum, and the ^{40}Ar/^{36}Ar intercept for MIL Plag. is clearly positive. The most reasonable interpretation of these MIL03346 data is that both WR and Plag samples contain excess (trapped) martian Ar, primarily released at lower extraction temperatures, and that for the WR sample, but probably not the Plag sample, significant ^{39}Ar recoil effects have also affected the age spectrum. This interpretation seems consistent with the fine grain size for MIL03346, and the observation that at high ^{39}Ar release the WR ages fall significantly below the Sm-Nd age. This interpretation is also consistent with the observation that all isochron-derived Ar-Ar ages for MIL03346 are slightly older than the Sm-Nd age, particularly for the WR sample, which has a larger ratio of trapped ^{40}Ar to in-situ-decay ^{40}Ar. For Y000593, we conclude that higher observed ages for both WR and Plag. samples are primarily caused by excess martian Ar and that recoil redistribution of ^{39}Ar plays only a minor role.

Excess ^{40}Ar. Table 1 also gives for these four samples the concentrations of excess ^{40}Ar (less the first extraction releasing significant terrestrial Ar) relative to the Sm-Nd isochron ages. Compared to the WR samples, the plagioclases contain not only higher ^{40}Ar concentrations, because of their higher K, but also excess ^{40}Ar concentrations that are larger by about an order of magnitude. The plagioclase/mesostasis in MIL03346 has been reported to comprise between 16% and 35% (average value ~ 23%) of the whole rock [8, 9, 10, 11, 12]. Plagioclase comprises ~5-10.5% of Y000593 WR [13, 14, 15]. ***Thus, it appears that plagiclase/mesostasis contains nearly all of the excess ^{40}Ar in these meteorites.*** The inference that late crystallizing phases contain the excess ^{40}Ar and the release of this component primarily from lower temperature sites suggest that the excess ^{40}Ar was present in the melt and became incorporated into the last crystallizing phases. The excess ^{40}Ar apparently was not acquired from the martian atmosphere by shock implantation. This conclusion may have implications for other trapped noble gases in nakhlites. MIL03346 cooled faster than Y000593 [16] and has a finer texture, which implies diffusion distances in the solid phase controlled retention of this excess ^{40}Ar*.

References: [1] Nyquist L. E. et al. (2001) *Space Science Reviews*. 96, 105-164; [2] Borg L. and Drake M. J. (2005) *JGR, 110*, E12S03; [3] Misawa K. et al. (2005) *Ant. Met. Res. 18*, 133-151; [4] Shih C.-Y. et al. (2006) *LPSC XXXVII*, #1701; [5] Bogard D. D. and Garrison D. H. (2006) *LPSC XXXVII*, #1108; [6] Garrison D. H. et al. (2000) *MAPS, 35*, 419-429; [7] Bogard D. D. and Garrison D. H. (1999) *MAPS, 34*, 451-473. [8] Anand M. et al. (2005) *LPSC XXXVI* . #1639; [9] McKay G. A. & Schwandt C. (2005) *LPSC XXXVI.* #2351; [10] Mikouchi T. et al. (2005) *LPSC XXXVI* . #1944; [11] Rutherford M. J. et al. (2005) *LPSC XXXVI.* #2233; [12] Stoper J. D. et al. (2005) *LPSC XXXVI*, #1547; [13] Mikouchi T. et al. (2002) *Ant. Met XXVII*, (abs) 83-85; [14] Mikouchi T. et al. (2003) *LPSC XXXIV*, #1883; [15] Imae N. et al. (2003) *Ant. Met. Res., 16*, 13-33; [16] McKay G. et al. (2006) *LPSC XXXVII* #2435.

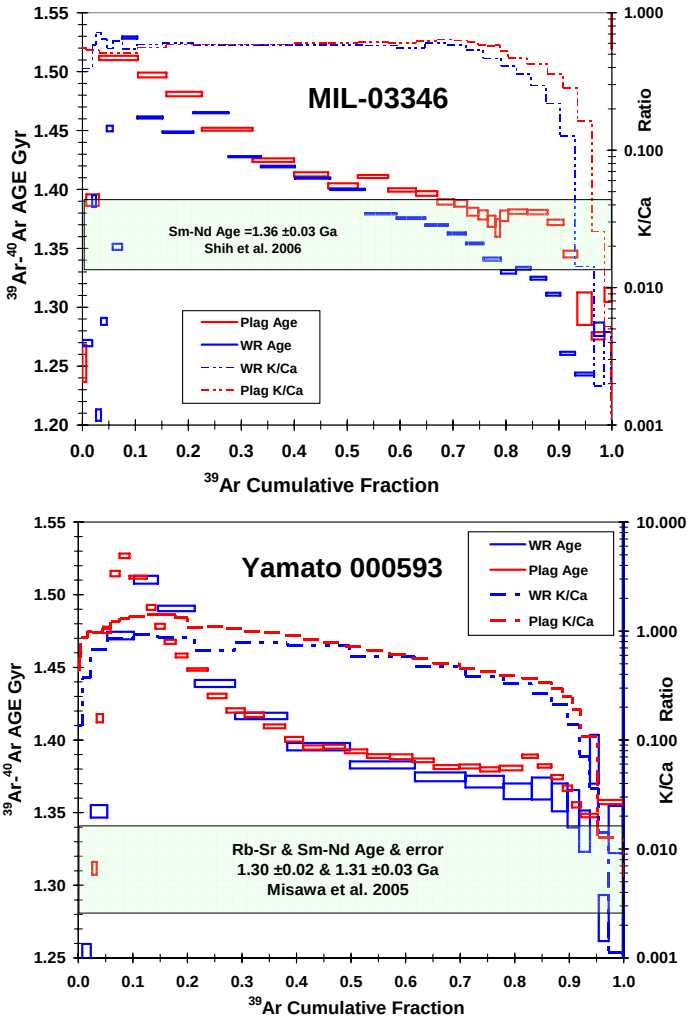

Table 1. ^{39}Ar-^{40}Ar Ages (Myr), Trapped ^{40}Ar/^{36}Ar Ratios, and Excess ^{40}Ar Concentrations in Whole Rock & Plagioclase.

Meteorite Phase	^{39}Ar Range	AGE, Myr	$(^{40}Ar/^{36}Ar)_I$	Excess ^{40}Ar
MIL03346 W.R.	(Sm-Nd age =1.36 ±0.03 Gyr)			5.2 e-7 cc/g
Cos-^{36}Ar Corr.	10-87%	1419 ±8	-1850 ±1003	(3.2% total)
Not Cos-Corr.	10-90%	1445 ±16	-1741 ±748	
MIL03346 Plag.				4.8 e-6 cc/g
Cos-^{36}Ar Corr.	3-73%	1382 ±6	2000 ±1174	(5.6% total)
Not Cos-Corr.	3-73%	1370 ±25	1448 ±1041	
Y000593 W.R.	(Sm-Nd age =1.31 ±0.03 Gyr)			7.2 e-7 cc/g
Cos-^{36}Ar Corr.	15-84%	1359 ±5	1502 ±159	(9.0% total)
Not Cos-Corr.	15-84%	1329 ±25	1225 ±474	
Y000593 Plag.				1.0 e-5 cc/g
Cos-^{36}Ar Corr.	7.5-84%	1434 ±12	-2290 ±12331	(9.2% total)
Not Cos-Corr.	7.5-84%	1444 ±19	-8039 ±5314	